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1

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TITLE: SOME MASSES FOR POPULATION I AND II CEPHEIDS

AUTHOR(S): Russell B. Kidman and Arthur N. Cox, T-6

MASTER

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

SOME MASSES FOR POPULATION I AND II CEPHEIDS

R. B. Kidman author
Theoretical Division, Los Alamos National Laboratory, University of
California

A. N. Cox
Theoretical Division, Los Alamos National Laboratory, University of
California

The masses of Cepheids can be obtained in several ways. If a Cepheid
luminosity is known from membership in a galactic cluster, the
mass-luminosity relation obtained from stellar evolution theory gives
its mass. This evolution mass depends slightly on the composition, that
is, the mass fraction of helium, Y, and on the the mass fraction of all
the heavier elements, Z, but as we shall see later, the composition
dependence is small.

A mass of a Cepheid that is based entirely on pulsation theory is called
the pulsation mass. Here the needed observations are: the luminosity,
the color (giving a surface effective temperature by use of a conversion
formula), and the easily observed pulsation period. In this report the
observed period is assumed to always be the fundamental mode for the
classical Cepheids. The mass, M, the pulsation constant, Q, and the
radius, R, are unknowns that are solved for using the three equations

$$L = 4\pi R^2 \sigma T_e^4 \quad , \quad Q = P(M/R^3)^{1/2} \quad , \text{ and } Q = Q(M,R,L,T_e) \quad .$$

These equations are: the definition of the effective temperature, the
period-mean density relation, and an expression fitting the pulsation
theory values for the pulsation constant Q obtained from a large number
of models covering a large range of stellar parameters.

A third mass can be derived based on both evolution and pulsation
theories. The required observations are only the well determined period
and a surface effective temperature. The above three equations, plus the
evolution mass-luminosity relation, are used to simultaneously solve for
the unknowns M, R, L, and Q. Due to the strong influence of the
evolution theory mass-luminosity relation for the theoretical mass, this
mass agrees to within a few % with the evolution mass for almost all
Cepheids. The major value of the theoretical mass is its availability
when a luminosity has not been observed, and one cannot get an evolution
mass.

These three masses have been calculated for 29 Cepheids recently listed
by Fernie and McGonegal (1983). The luminosities of these Cepheids have
been uniformly set by assuming a distance modulus of 3.29 for the Hyades
cluster. Table 1 gives our evolution, theoretical, and pulsation masses.
Fernie and McGonegal have suggested that CS Vel and V810 Cen are not in

the cluster as supposed, and therefore their luminosities are
incorrectly stated. Due to the large discrepancy between the evolution
and pulsation masses for V Cen, GY Sge, and S Vul, we have rejected them
also. We find only a small difference between the masses for TW Nor,
and therefore we do not reject this Cepheid even though there is a
cluster membership question about it. The ratios of these masses
relative to the theoretical masses average to the values at the bottom
of the evolution and pulsation mass columns. The usual scatter in the
pulsation masses is present, but on the average, the masses seem in
accord with evolution theory.

Table 2 gives similar results with only the distance scale to the Hyades
changed to 3.45, a value recently suggested by Vandenberg and Bridges
(1984). With the increased luminosities, evolution masses increase a
bit, while the luminosity-independent theoretical masses remain unchang-
ed. However, pulsation masses are greatly increased so that the average
is about 1.22 above the theoretical masses. For both these tables we
have converted the dereddened (B-V) colors to effective temperatures by
use of the Kraft (1961) formula. As discussed by Cox (1979) and many
others such as Pel (1978) these temperatures may need to be cooled by
0.01 to 0.03 in log T_e. That would greatly alleviate the mass discrepan-
cy. It appears that a distance scale which has the Hyade distance
modulus at 3.45 is too large, but part of the change from the currently
used 3.29 may be acceptable from the viewpoint of Cepheid masses.

Other recent data on Cepheid luminosities have been prepared for
publication by Schmidt (1984). Table 3 shows at the top section the
evolution, theoretical, and pulsation masses for 7 Cepheids using his
luminosities and dereddened colors. The pulsation masses are so low that
for conventional compositions, stars would not evolve into the
instability strip. The possible cooling of the temperature scale is
investigated in the second section. Even though we have reduced the log

Table 1

T_e by only 0.01, it is apparent that more than three times this amount is needed to reconcile Schmidt's low pulsation masses. With the use of the Becker, Iben and Tuggle (1977) fits for the second crossing luminosities as a function of composition and mass, we give the lower two sections for, respectively, higher Y and lower Z. These extreme composition changes for population I Cepheids do not lower the evolution masses enough to match the Schmidt pulsation masses. We feel that his luminosities are very much too low.

Anomalous Cepheids have periods like RR Lyrae variables, but they are typically 5 times more luminous. Zinn and King (1982) have proposed that variable V19 in NGC 5466 at 0.82 day is pulsating in the first radial overtone mode, but even with that mode, its mass is about 1.4 $M_\odot$. This is surprising for a population II star because it is believed that stars

Table 2

Fernie and McGonegal Data
$(m-M)_{[illegible]}=3.46$

Cepheid	P(d)	T_e(K)	$L/L_\odot$	M_{ev}	M_{th}	M_Q
SU CAS	1.95	[illegible]	917	4.8	4.0	[illegible]
EV SCT	3.09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CE CAS B	4.48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CF CAS	4.88	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CE CAS A	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
UY PER	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CV MON	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
V CEN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
VY PER	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CS VEL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
V367 SCT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
U SGR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DL CAS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.0
S NOR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.0
TW NOR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
VX PER	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.0
SZ CAS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
VY CAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
RU SCT	[illegible]	[illegible]	[illegible]	10.7	[illegible]	[illegible]
RZ VEL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WZ SGR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SW VEL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
T MON	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
KQ SCO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] PUP	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SV VUL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
GY SGR	[illegible]	[illegible]	47871	[illegible]	[illegible]	[illegible]
S VUL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
V810 CEN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]		[illegible]

Table 3

Schmidt Photometry and Kraft Temperatures

Cepheid	P(d)	T_e(K)	$L/L_\odot$	M_{ev}	M_{th}	M_Q
		Y=[illegible]	Z=[illegible]			
EV SCT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] CAS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CV MON	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
U SGR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DL CAS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
S NOR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TW NOR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		T_e cooler by 0.01 in logT_e				
		Y=[illegible]	Z=[illegible]			
EV SCT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] CAS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CV MON	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
U SGR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DL CAS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
S NOR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TW NOR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Y=[illegible]	Z=[illegible]			
EV SCT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] CAS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CV MON	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
U SGR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DL CAS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
S NOR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TW NOR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Y=[illegible]	Z=[illegible]			
EV SCT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] CAS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CV MON	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
U SGR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DL CAS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
S NOR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TW NOR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

more massive than about 0.8 M_θ should have long ago died. We here confirm the proposal that this star is the result of a coalescence of two stars in a binary system that had an initial separation smaller than the red giant radius of the more massive star.

Figure 1 gives the work done in each of the 195 zones over each pulsation cycle to cause pulsations in each of the three lowest radial modes. The mass used for this nonadiabatic pulsation analysis is 1.4 M_θ, and the luminosity is the observed 257 suns. The typical population II composition used is the King Ia table with $Z=0.001$. Here at 7500K, hotter than NGC 5466 V19, all modes are stable because the radiative damping of the interior (lower zone number) layers is greater than the hydrogen and helium driving in the surface layers.

Figure 2 gives the same plot for the effective temperature of 6500K. In this case it is apparent that the first and second overtone modes are driven more than they are damped, and linear theory predicts growing pulsations. Actually the first overtone is driven the strongest, and at the observed effective temperature of 7000K, probably only the first overtone is unstable to pulsations.

Fig. 1. The work per pulsation cycle to drive pulsations in a NGC 5466 V19 model at 7500K is plotted for each of the 195 zones.
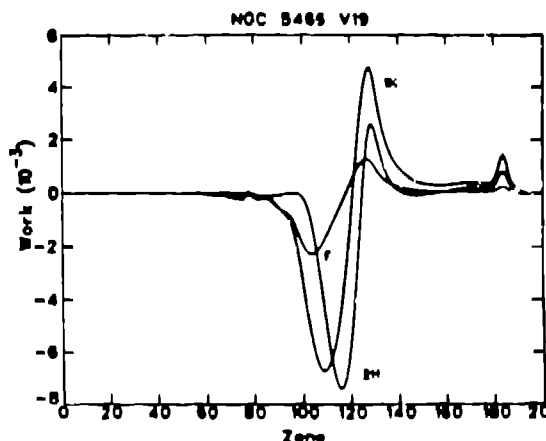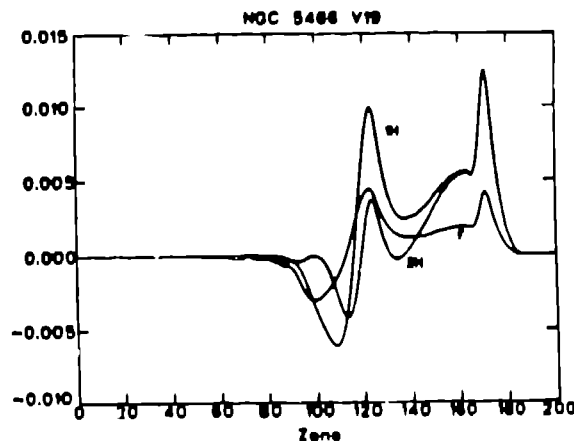
Fig. 2. The work per pulsation cycle to drive pulsations in a NGC 5466 V19 model at 6500K is plotted for each of the 195 zones.

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